METHODS AND COSTS OF SINKING A CIRCULAR CONCRETE-LINED VENTILATION SHAFT

By Lloyd Williams

* * * * * * * * * * * * information circular 7955

UNITED STATES DEPARTMENT OF THE INTERIOR
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BUREAU OF MINES
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METHODS AND COSTS OF SINKING A CIRCULAR CONCRETE-LINED VENTILATION SHAFT[1]

by

Lloyd Williams[2]

SUMMARY

A vertical air shaft in the Birmingham, Ala., iron district was sunk with a circular cross section and lined with concrete at a relatively low cost to provide needed ventilation for an iron-ore mine. The method of sinking the shaft is described, and the costs are stated in man-hours with a descriptive list of equipment and a statement on the size and use of temporary buildings.

Preparation began May 2, 1955, and the shaft was completed at a depth of 1,680 feet by September 22, 1956. By October 1956, all temporary building and shaft-sinking equipment had been removed. The total direct-labor cost for the operation, including preparation and dismantling, was 50,700 man-hours, or 30.2 man-hours per foot. Total rock and dirt removed amounted to 17,523 cubic yards (in place), and the shaft lining required 4,635 cubic yards of concrete to form a circular air shaft with an inside diameter of 16 feet.

INTRODUCTION

This paper is one of a series of Information Circulars being published by the Bureau of Mines on mining methods, practices, and costs. It describes the sinking of a circular air shaft and the pouring of a smooth concrete lining to facilitate the movement of mine air to the surface. The operation was selected for study as an example of an efficient low-cost ventilation shaft. This was the third circular concrete-lined shaft of similar design sunk by Cowin and Co., Inc., Mining Engineers and Contractors of Birmingham, Ala.

The shaft site is approximately 7 miles south of the center of Birmingham, Ala., and 8 miles by road east of Bessemer, Ala. (See figure 1.)

ACKNOWLEDGMENTS

Information used in preparing this circular was furnished by Cowin and Co., Inc., Mining Engineers and Contractors, Birmingham, Ala. The cooperation and personal assistance of John J. Cowin is gratefully acknowledged. Photographs appearing as figure 5, 7, 10, 14, and 16 were provided by Cowin and Co.

1/ Work on manuscript completed March 1958.

2/ Mining engineer, Bureau of Mines, Region V, Norris, Tenn.

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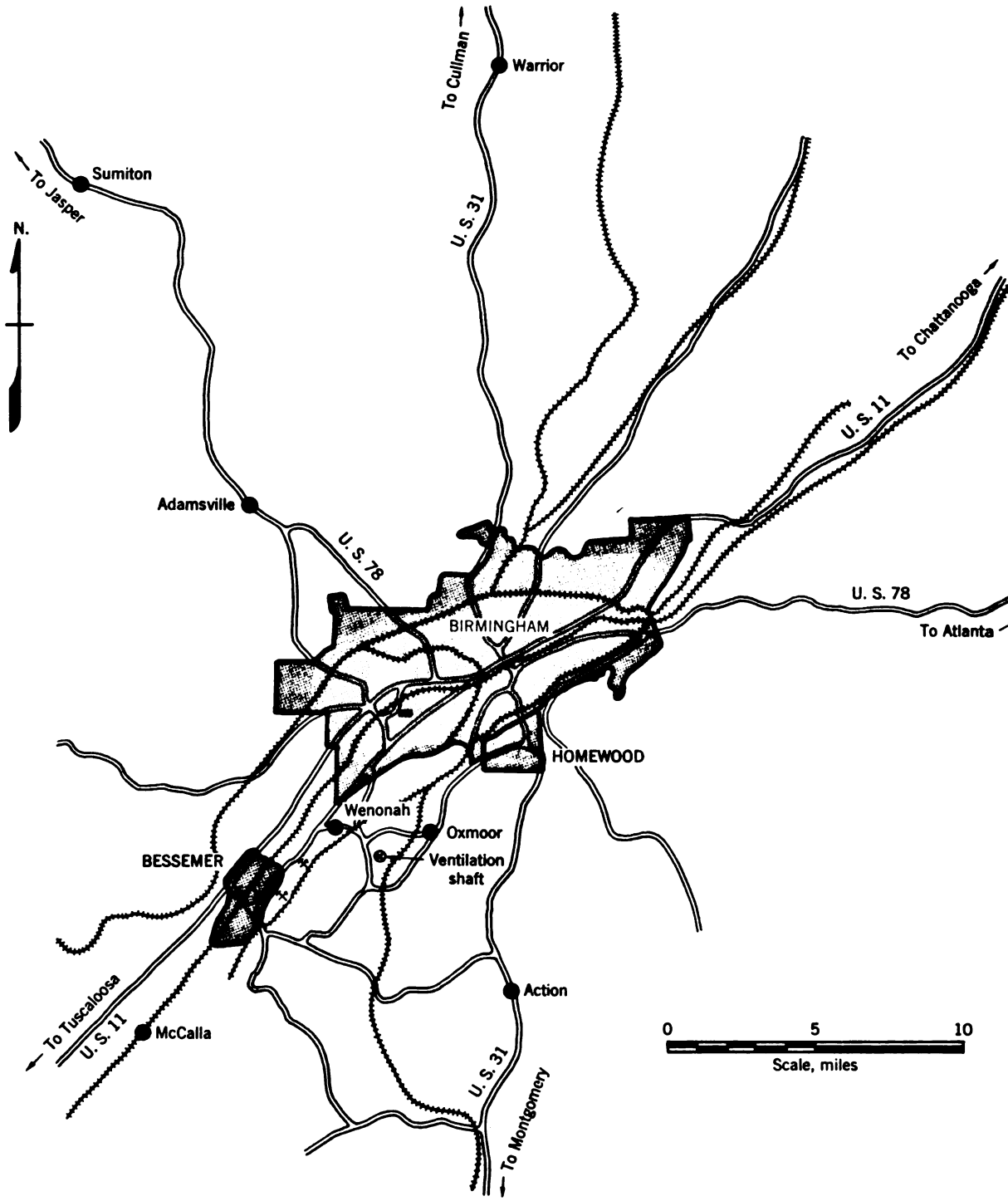

FIGURE 1. - Location Map of Ventilation Shaft.

PURPOSE OF SHAFT

The need for additional ventilation at a Birmingham-district iron mine required sinking a vertical shaft to a depth of 1,680 feet below the surface.

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A concrete-lined vertical shaft with a 16-foot inside diameter was designed to handle approximately 500,000 cubic feet of air per minute, to be exhausted at 4-1/2-inch water gage with two vertically mounted 8-foot-diameter surface fans, each powered by a 300-hp. a.c. motor. Most of the supplies and materials were furnished by the prime contractor, Cowin and Co., Inc. The mining company furnished the electric power, 2,300 volts, 60-cycle a.c., at the shaft site and also supplied such items as drawings, grades, grouting materials, and roof bolts for the shaft bottom.

GEOLOGY

The shaft was sunk entirely in Paleozoic rock, starting in the Little Shades sandstone of Mississippian age and continuing downward through predominantly shaly strata and minor sections of interbedded limestone (fig. 2). Approximately 100 feet of chert was encountered about 200 feet above the ore. The structure of the formations was generally strong down to a depth of 1,250 feet, where weaker rock was encountered for approximately 250 feet, after which the rock structure was found to be stronger down through the Fort Payne chert and into the Frog Mountain formation of the Lower Devonian series. The shaft was completed in the Red Mountain (Clinton or Rockwood) formation of the Silurian system.

The iron ores in the Birmingham district of Alabama are found in the Red Mountain (Clinton or Rockwood) formation, a member of the Niagara group in the Silurian system.3/ Four horizons of iron-bearing rock occur in the formation. The Irondale is the lowest and is mined in some localities. About 25 to 30 feet higher is the Big Seam, which is the most extensively mined iron-ore bed in the Birmingham district. Above the Big Seam in ascending order are the Ida and Hickory Nut Seams. Although ore has been mined from the Ida Seam, it is of doubtful value. The Hickory Nut Seam is a ferruginous sandstone and is not considered ore.

Immediately above the Silurian, the Devonian system is represented in this shaft by only 3 or 4 feet of Frog Mountain sandstone. The Carboniferous is represented by Mississippian formations extending from the Chattanooga Shale up to and including the Little Shades Mountain sandstone. The formations are generally horizontal.

PREPARATION FOR SHAFT SINKING

A site for the air shaft was selected by the mining company. Plans and specifications were drawn up and sent out to qualified contractors in December 1954 for bidding. Cowin and Co., Inc., Mining Engineers and Contractors, were the low bidders and received the contract. A graded gravel road from the public road to the site was constructed by the mining company or purchaser, and the contractor started surface installations May 2, 1955.

3/ Adams, G. I., Botts, Charles, Stevenson, L. W., and Cooke, Wythe: Geology of Alabama. Geologic Survey of Alabama Special Rept. No. 14, 1926, 312 pp.

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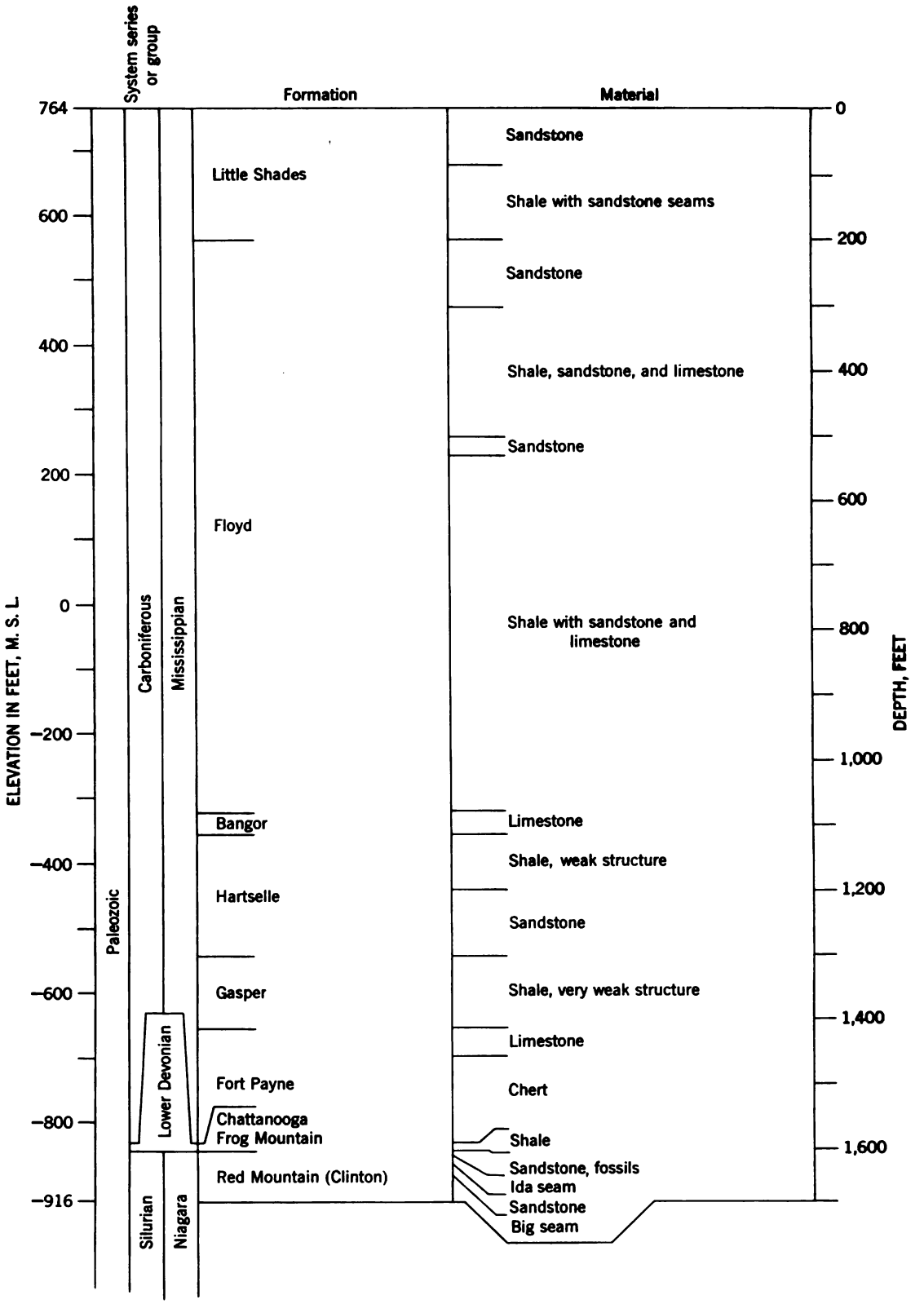

FIGURE 2. - Approximate Geologic Section of Ventilation Shaft.
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Four holes were drilled within 10 feet of the shaft limits and grouted for the purpose of excluding ground water from the shaft. The work was subcontracted to Joy Manufacturing Co., who used their size N diamond bit. The depth of each hole was (1) 120 feet, (2) 129 feet, (3) 142 feet, and (4) 200 feet, totaling 591 feet for the four holes. The grout, which was a mixture of one volume of sand to one of cement with about 1.5 percent bentonite, was prepared in two 15-cubic-foot circular mixing tanks. Each tank was equipped with an air motor which, through an arrangement of gears and shafts, operated a propeller suspended in a horizontal position about 2 inches above the bottom of the tank. The grout was pumped into the holes under a pressure of 150 p.s.i.

Four buildings were erected: (1) Hoist house (30 ft. by 30 ft.) with one 300 hp. hoist; (2) compressor house (30 ft. by 20 ft.) with two compressors and one 100 hp. hoist; (3) field office and supply house (20 ft. by 40 ft.); and (4) change house (40 ft. by 20 ft. with a 16 ft. by 10 ft. extension for showers). (See figure 3.) A temporary steel headframe with two 48-inch sheave wheels and an overall height of 38 feet was erected (figs. 4 and 5). An area sloping away from the shaft provided enough space within 700 feet of the shaft for the disposal of all excavated material from the shaft without interfering with surface drainage.

Installation of the shaft collar progressed along with the other preparation work and is grouped with surface installations under costs in man-hours. However, description of the method of installation is under shaft sinking, as the collar was structurally integrated with the main body of the shaft. The shaft collar was completed by June 21, 1955, and the headframe was erected by June 27, 1955.

Principal equipment used to sink the shaft consists of the items listed and described in table 1.

TABLE 1. - Description of equipment

Quantity	Name and description
3.....	Compressor--Ingersoll-Rand type 40, 75H compressor; 80- to 125-p.s.i. pressure, stationary, air-cooled, 2-stage piston; 4 low-pressure 7-1/2-in.-bore by 5-in.-stroke cylinders; 445-c.f.m. piston displacement; 870 r.p.m. with 75-hp. General Electric 200-v. 60-cycle a.c. 3-phase motor; wt. 3,960 lb.; 2 in regular use and 1 standby.
1.....	Hoist--5-foot-diameter, single drum; electric brakes and emergency brakes; 10,000-lb. load; 1,100-f.p.m. speed; 1-1/8-in. steel rope; 300-hp. General Electric 2,200-v. 60-cycle a.c. 3-phase induction motor; main hoist.
1.....	Hoist--Ottumwa Iron Works hoist; 3-ft. single-drum mechanical brakes; 400-f.p.m. speed; 1-1/8-in. steel rope; 100-hp. General Electric a.c. 60-cycle motor; auxiliary hoist.

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TABLE 1. - Description of equipment (Con.)

Quantity	Name and description
1.....	Jumbo--4-legged pipe frame with 4-ft. spread at base; overall height 12 ft.; equipped with air-line lubricator and 4 85-1/2-in.-screw-activated drill arms. Each arm has independent swivel at top and dual turning mechanism at end to permit universal turning motion for drilling machines.
4.....	Drilling machine--Ingersoll-Rand DA 35; requires pressure of 90 p.s.i.; uses 8-ft.-long 1-1/4-in.-round steel; operates on chain-feed carriage permitting drill to travel 8 feet.
1.....	Mucking machine--5/8-cu.-yd. Blaw Knox clamshell; suspended on cables; operated by 2 air tuggers remote-controlled from shaft bottom.
1.....	Diamond drill--E. J. Longyear; air-driven.
2.....	Air hoist--Ingersoll-Rand, K4UL utility hoist; 3,500-lb. lift operating at pressure of 80 p.s.i.; speed of 95 f.p.m.; 1/2-in.-cable; wt. 950 lb.; operates mucking machine.
1.....	Air hoist--Ingersoll-Rand EUL utility hoist; 2,000-lb. lift operating at pressure of 80 p.s.i.; speed of 54 f.p.m.; 1/2-in. cable; wt. 440 lb.; operates shaft doors.
2.....	Truck--1955 Ford with 4-yard dump body; 1955 Chevrolet with 4-yard dump body.
1.....	Sump pump--Ingersoll-Rand, size 35; pneumatically driven; 1-in. air inlet and 1-1/4-in. exhaust; 2-1/2-in.-pipe tap discharge; wt. 28 lb.; overall height 28 in.
1.....	Water pump--gasoline-driven piston pump; 1-in. outlet.
1.....	Grout pump--Gardner-Denver air duplex plunger C; 6-in.-diameter air piston; 4-in.-diameter pump plunger; 6-in. stroke.
1.....	Shaft bucket--overturning type with a capacity of 56 cu. ft.
1.....	Air fan--25 hp. centrifugal Coppus blower fitted for 18-in. tubing.
1.....	Impact wrench--Ingersoll-Rand size 577; air-operated; 2-in.-bolt capacity; 550 r.p.m.; 500 impacts per minute.
2.....	Vibrator--Ingersoll-Rand 2V; overall length, 86 in.; vibrating unit, 18-3/4-in. long, 4-1/8-in. diameter; wt. 34 lb.; 6,000 v.p.m. at 90 p.s.i. pressure.

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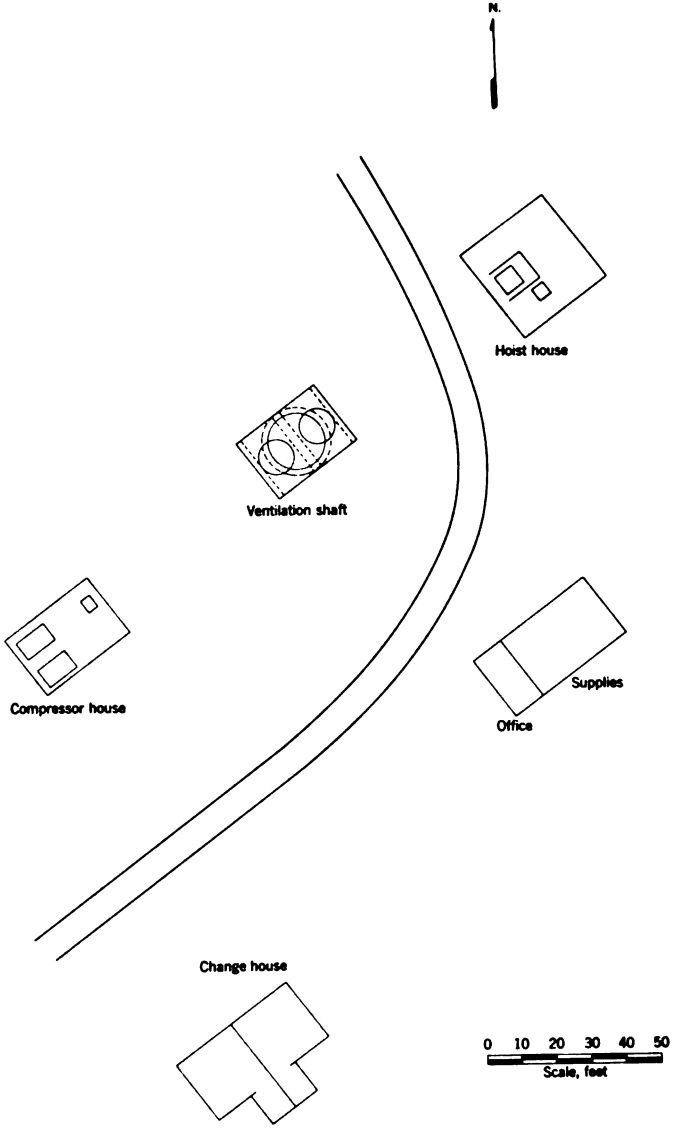

FIGURE 3. - Site of Ventilation Shaft and Temporary Buildings.
(Data furnished by Cowin and Co.)

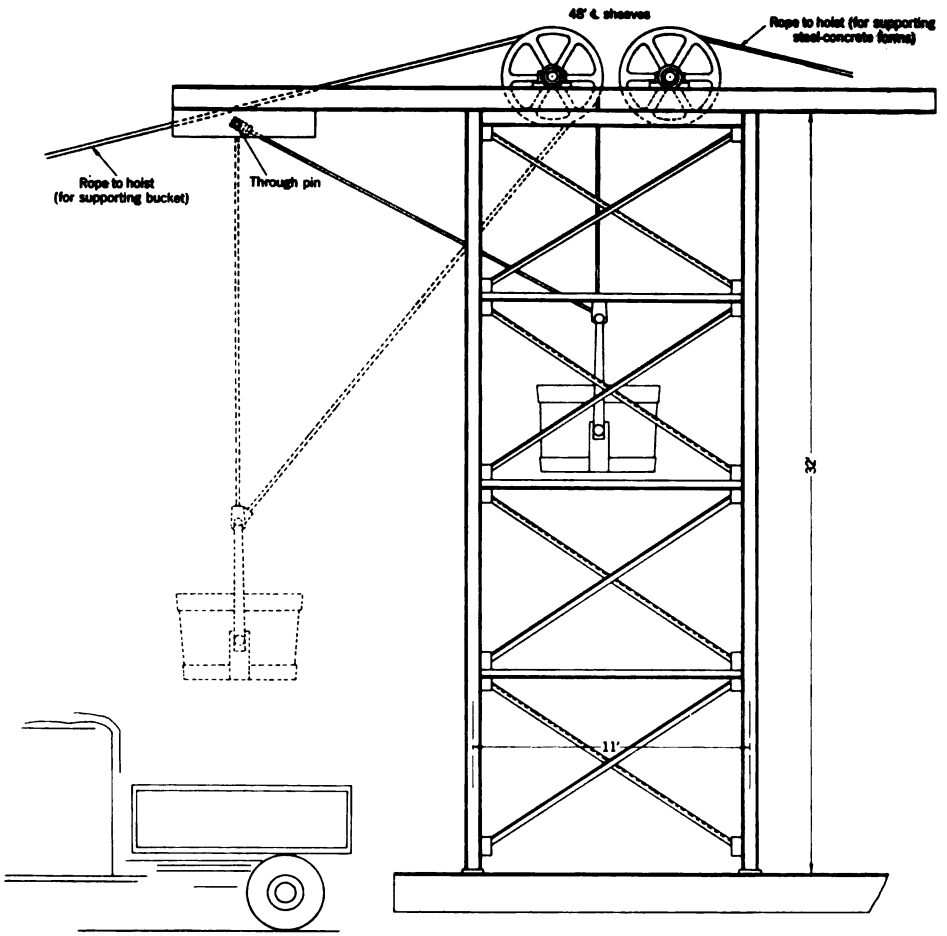

FIGURE 4. - Design of Temporary Headframe.
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FIGURE 5. - View of Temporary Headframe.

SHAFT SINKING

Shaft Design

The main body of the shaft is a concrete-lined vertical opening, circular in shape, with an inside diameter of 16 feet. The overall depth is 1,680 feet, of which 40 feet is shaft collar, 1,614 feet is the main body, and 26 feet is shaft bottom.

The shaft collar is designed with a flared oval-shaped concrete-lined opening, with a horizontal inside measurement of 24 feet by 16 feet at the top. It converges within a distance of 10.7 feet into a 16-foot-inside diameter concrete-lined shaft which continues for the remainder of the 40 feet of shaft collar and the 1,614 feet of main shaft. (Figs. 6 and 7.) The weak

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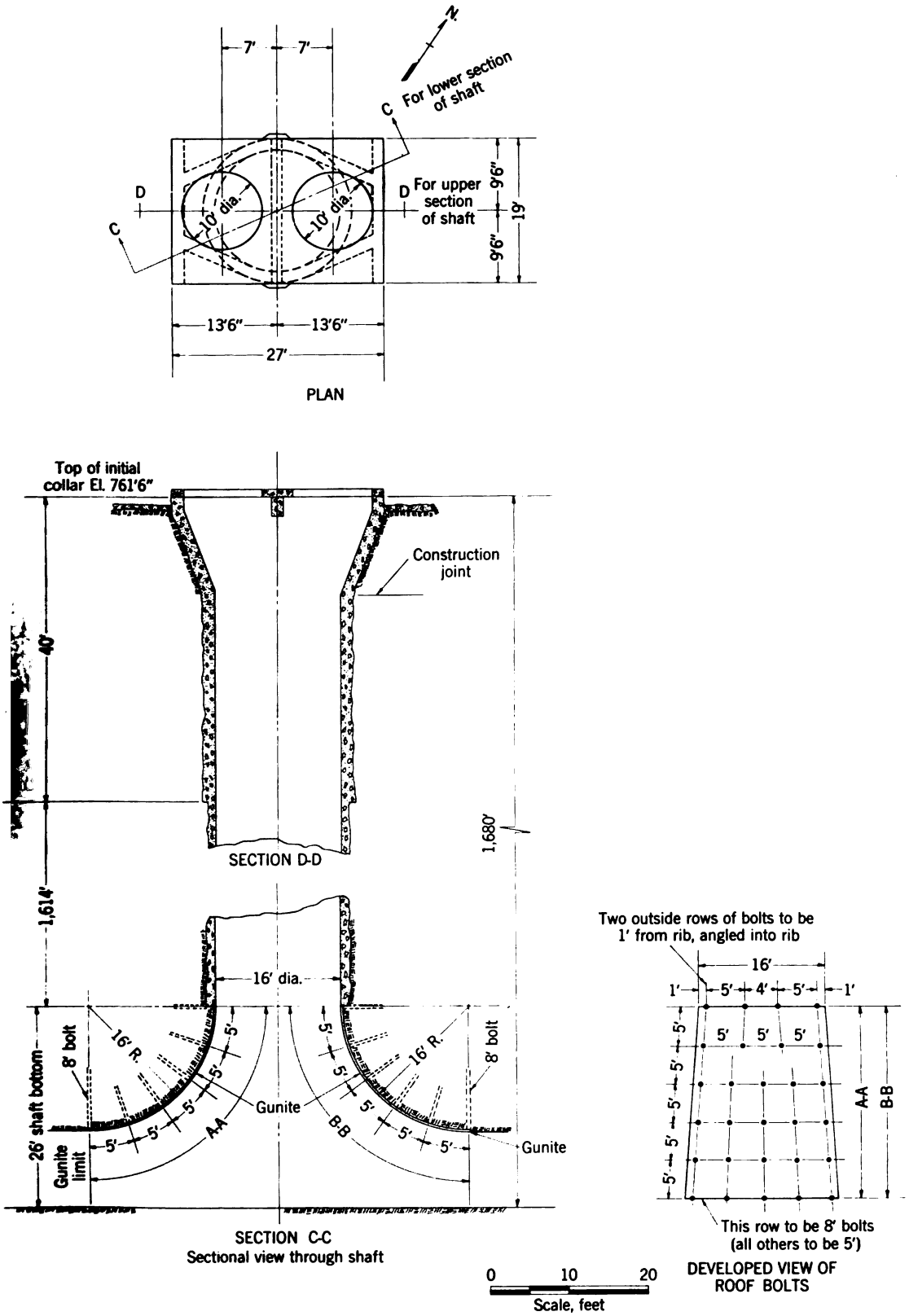

FIGURE 6 - Design of Ventilation Shaft.
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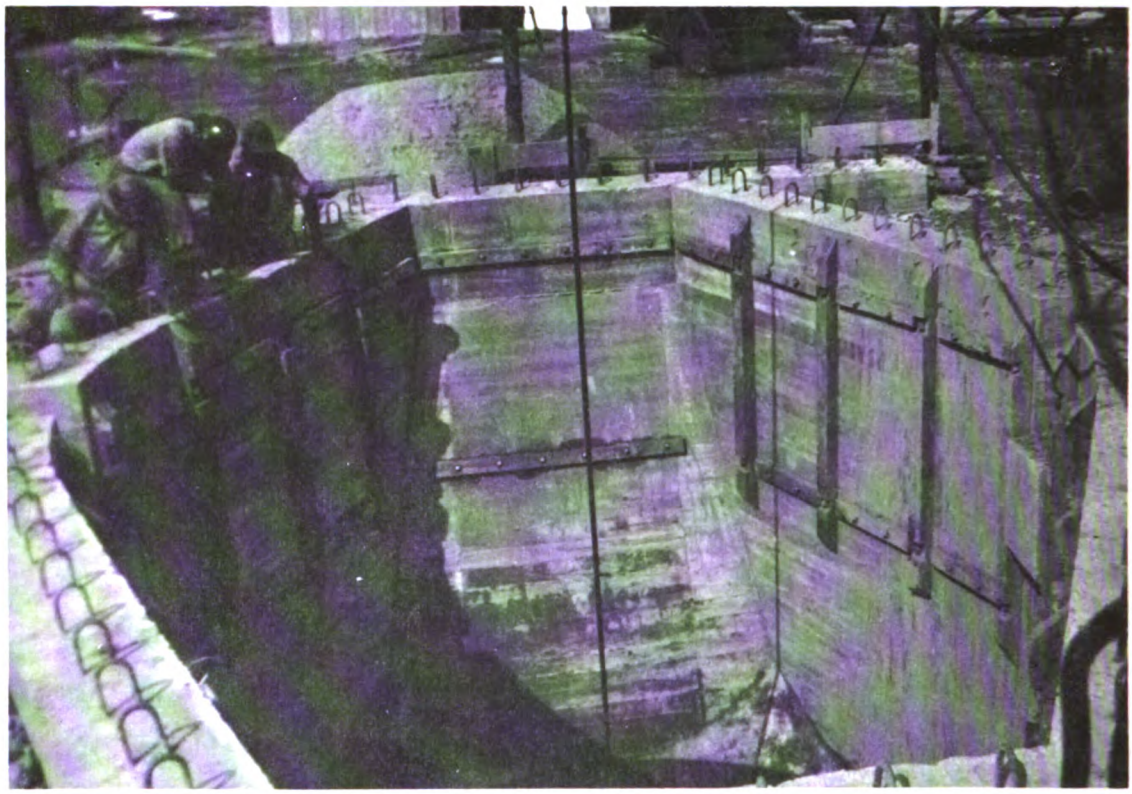

FIGURE 7. - View of Shaft Collar.

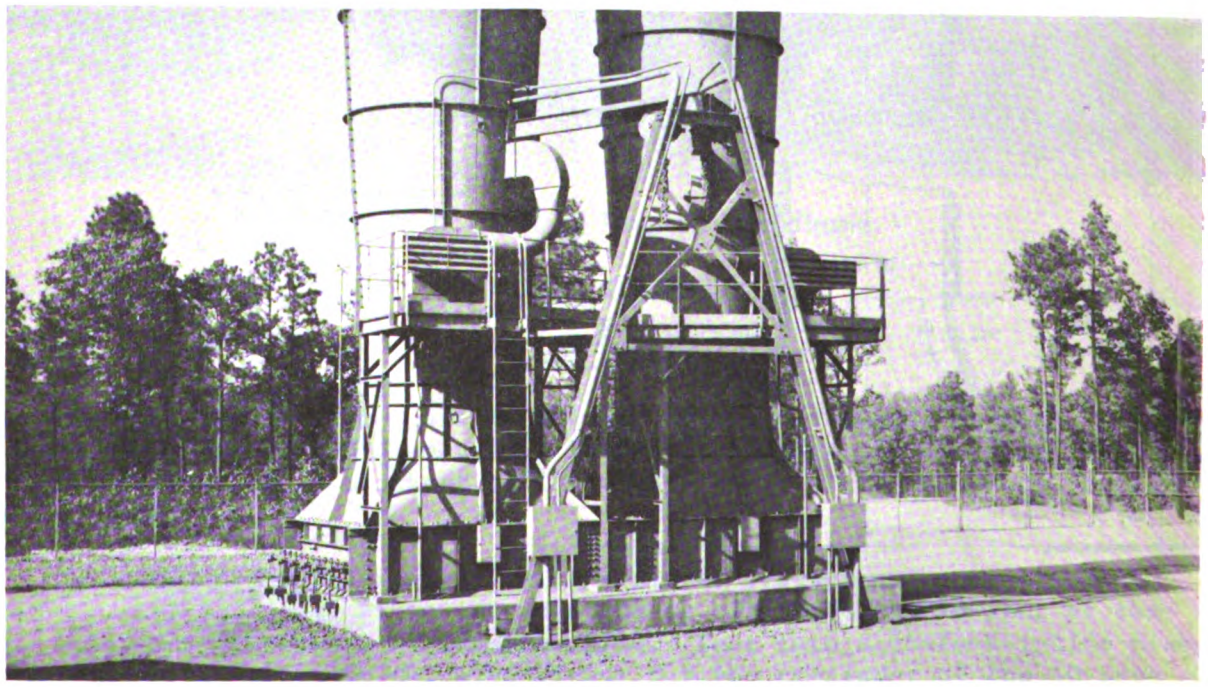

FIGURE 8. - View of Vertically Mounted Fans.

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physical condition of the ground was the primary reason for extending the shaft collar to 40 feet below the surface. The lower 29.3 feet of the distance is identical in construction to the main body of the shaft, except that the concrete lining is thicker in the collar. An 18- by 30-inch concrete beam was installed across the top of the opening after the shaft was completed to assist in the support of a reinforced concrete cover with two 10-foot-diameter fan openings. Two 8-foot-diameter mine-ventilation fans are vertically mounted over the openings (fig. 8).

The circular shape of the shaft eliminates the need of steel sets or reinforcing rods in the lining, as compression is the only force exerted on the lining except in the flared part of the collar, which is reinforced.

The main body of the shaft extends downward 1,614 feet from the portion described as the shaft collar and was excavated with a minimum diameter of 18 feet to meet specifications of a 16-foot-inside-diameter circular shaft with a minimum 12-inch-thick concrete lining. Concrete specifications were for a minimum compressive strength of 3,000 pounds per square inch, and aggregate proportion by volume, one part portland cement (a minimum of 6 sacks per yard of concrete), 1-1/2 parts sand, and 3 parts gravel with water not to exceed 6-1/2 gallons per sack of cement. A substantial and durable lining, free of voids and unbonded joints and having a smooth surface, was specified. Joints between successive pours were required to be made or ground smooth within a tolerance of half an inch, and forms were to be constructed to prevent deviation from the circular shape and tight enough to prevent loss of grout. Ready-mixed concrete was used and delivered on a schedule that provided 1 hour maximum mixing time.

The bottom 26 feet of the shaft is "belled out" in a longitudinal section with two 16-foot-radius curves to form a smooth connection between the side walls of the shaft and the top of the drift (fig. 6). The elimination of sharp corners reduced airflow resistance. Each side is supported by reinforced gunite anchored to the natural top with 23 5-foot roof bolts and 5 8-foot roof bolts. The gunite was a mixture of three parts sand to one part cement, applied pneumatically.

Collar Installation

A 40-foot-deep excavation was made for the shaft collar by a subcontractor who removed 253 cubic yards of dirt and 189 cubic yards of rock with a Marion crane equipped with a 1-1/4-cubic-yard clamshell bucket. The prime contractor placed the forms and poured 175 cubic yards of concrete for the lining. This work was done concurrently with surface installations by a single shift of 5 to 10 men. The cost in man-hours is therefore grouped with surface installations. Lining the shaft collar with concrete was completed about 5 days before the headframe on the surface was erected.

Sinking Practice

After the shaft collar was completed, a double shift was started with full crews. Drilling was done on the night shift with seven men: One foreman,

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one hoistman, four drillers, and one drill helper. A day-shift crew of eight men (foreman, hoistman, truckdriver, topman, miner, tugger operator, and two muckers) took care of the mucking.

Drilling and Blasting

The drill-hole pattern was a modified conical cut with 1 buster hole in the center, 6 cut holes, 10 first-relief holes, 16 second-relief holes, and 22 ring holes, or a total of 55 holes (fig. 9). The number of holes varied occasionally according to condition of the rock. A triangular template with a radius of 8 feet 10 inches and a base of 2 feet 6 inches was used to spot and space the ring holes (fig. 9). The center or axis of the template was the center or buster hole, which was drilled in the center of the shaft before the jumbo was set up. The template was then rotated to spot and space the ring holes along the circumference of the shaft. Further efficiency was accomplished by the use of the four-machine jumbo, which was designed for precise drilling, eliminating dependence on the drillers' judgment to aline each hole (fig. 10). The drilling machines and carriages were mounted on fixed-length arms, which extended radially from individual swivels located 15 inches from the center of the jumbo. (See table 1 for description.) The angle between the extended centerline of the arm and the projected centerline of the drill carriage was predetermined by calculation to give the cut holes a sufficient vertical angle, dependent on the clearance of the shaft walls. This angle was maintained for all holes. The pitch for each circle of holes was set by adjusting the angle between the arm and the jumbo by operation of a worm-screw control. However, the design of the jumbo with the arm swivels located off-center required minor adjustments of the arms for holes located near the extremities of the drilling quadrants to compensate for the difference in radii of the arms and the centerline of the shaft. The cut holes and first-relief holes were drilled 18 inches deeper than the others to maintain a sump in the center of the shaft for

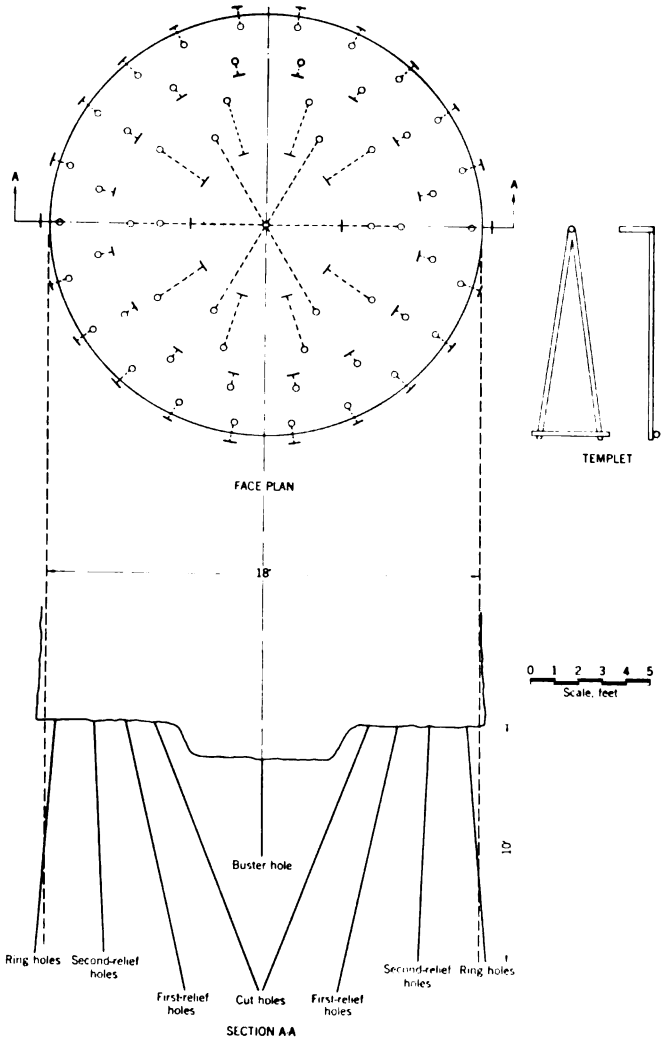

FIGURE 9. - Sketch Showing Drill-Hole Pattern and Template.
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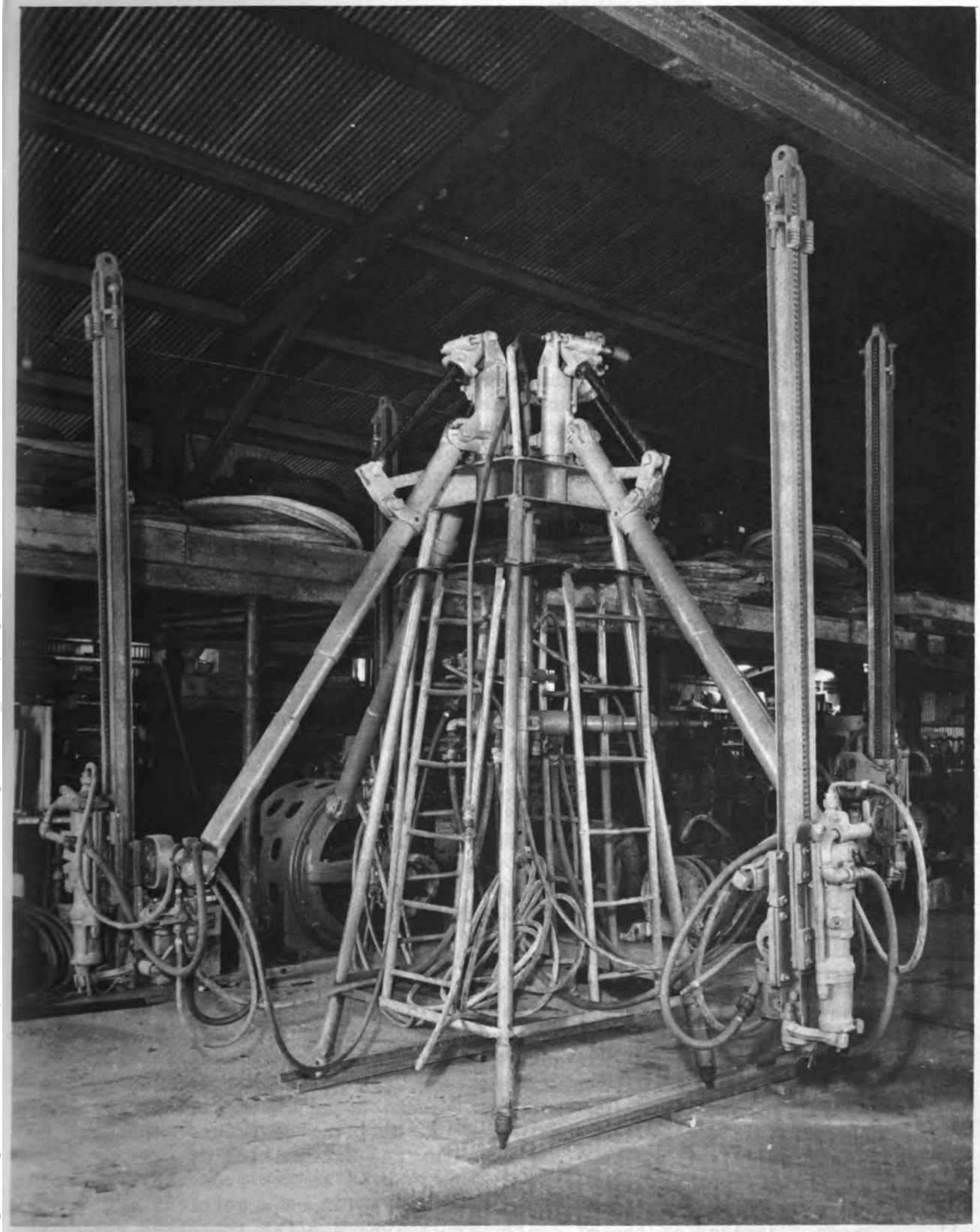

FIGURE 10. - View of Jumbo Supporting Drilling Machines.

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dewatering and easier clamshell operation when mucking. The average advance of a cut for the whole shaft was 8 feet. However, the shaft was advanced 9 to 10 feet per cut to a depth of 1,350 feet. After that the advance per cut was 5 to 6 feet.

A drilling procedure based on calculated distances and angles for a typical 10-foot-deep cut follows: A short 5-foot buster hole was drilled on the centerline of the shaft, and the pivot of the drilling template was placed in the hole and rotated around the shaft for the purpose of marking the spacing of the 22 ring holes. The jumbo was then set up, centered over the buster hole, and leveled. The arms were swung outward to a convenient position for mounting the drill carriages, which were set at a fixed angle of 52 degrees from the arms. This angle was maintained for all holes. The machines then were raised on the carriages, and the drill steel was inserted. After the machines were swung to the approximate center of each drilling quadrant, the vertical angle between the jumbo and the arm was adjusted so that the holes were started 102-1/2 inches from the centerline of the shaft and spaced 29 inches from each other. This placed the holes at an outward angle of 4.6 degrees from the vertical. Three to 4 holes were drilled within 45 inches of the center of each quadrant to a depth of 120 inches, placing the bottoms of the holes 32 inches from each other and 111 to 112 inches from the center of the shaft. The change in distance was caused by the offcenter arm swivel. The remaining eight holes at the extremities of the drilling quadrants were drilled by raising the arms and increasing the angle between the arms and the jumbo so that the holes were started 100 inches from the centerline of the shaft. This changed the vertical angle of the holes to 5.3 degrees, and put the bottoms of these holes at the same spacing as the other 14 holes.

The 16 second-relief holes were spaced 33 inches apart. Eight of the holes were started by spotting them 16-1/2 inches right and left from the center of each drilling quadrant, and 85 inches from the centerline of the shaft. This put the drill on an inward angle of 3.4 degrees from the vertical. The other eight holes were spotted 33 inches from the first eight, and 84 inches from the centerline of the shaft, which, owing to the offcenter arm swivel, required raising the arms and changing the vertical angle of the holes to 2.9 degrees. Drilling the 16 holes to a depth of 120 inches placed the bottoms at a distance of 78 inches from the center of the shaft and spaced 30-1/2 inches from each other.

The 10 first-relief holes, spaced 42 inches apart, were started by swinging the machines back to the center of the drilling quadrant and lowering the arms to a position where the drill intersected the shaft bottom at a point 68 inches from the shaft centerline. This put the drill carriage at an angle of 12.3 degrees from the vertical. From this setting, two holes were drilled at the center of two opposite drilling quadrants, and 4 holes were drilled 21 inches right and left of the center of the other two drilling quadrants. Due to the offcenter arm swivel, the other four holes at the extremities of two opposite drilling quadrants were started at a distance of 66 inches from the centerline of the shaft by raising the arms, which put the holes on a vertical angle of 11.6 degrees. Because of the offcenter arm swivel and the increased vertical angle, the drill carriages were turned so that the holes were on a plane with the centerline of the shaft. Drilling these holes to a length of 141 inches

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put the bottoms of the holes 41 to 42 inches from the center of the shaft, 26 inches from each other, and 138 inches below the shaft bottom. The additional depth provided for an 18-inch-deep sump in the center of the projected bottom.

Preparation for the six cut holes, which were 60 degrees apart, placed two of the holes in the center of opposite drilling quadrants, and the remaining four holes were placed 30 degrees to the right and to the left of the center of the other two drilling quadrants. The arms of two opposite drills were dropped to start the two holes in the center of the drilling quadrants at a distance of 52-1/2 inches from the centerline of the shaft, which put the holes on an angle of 20.8 degrees from the vertical. The starting points of the other four holes were spotted by measuring 51 inches to the right and left of the first two holes, and 51 inches from the centerline of the shaft, placing them in the two adjacent drilling quadrants. The drilling arms in these quadrants were dropped to start at these points, and the drill carriages were turned to place the holes in a common plane with the centerline of the shaft. This put the holes on an angle of 20.3 degrees from the vertical. All six holes were drilled 147 inches, met at the centerline of the shaft at a vertical depth of 138 inches from the shaft bottom, or 120 inches from the bottom of the sump, and provided for continuation of an 18-inch sump as shaft-sinking progressed.

The drilling procedure described above for angles, distances, etc., can also be calculated. See appendix for calculations.

Each machine was operated by one driller who covered approximately one quadrant of the circular cut. One drill helper aided the drillers when changing steel, etc. The shaft walls were occasionally scaled to keep them free of loose rock. A foreman supervised the work, and a hoistman stayed at the top to operate the hoist on signal. Men, equipment, and supplies were lowered and hoisted in the same bucket that was used for hoisting muck.

Air was furnished to the drilling machines at 90 p.s.i. through a 2-1/2-inch pipe from two 75 hp. compressors on the surface. (See table 1.) Water was pumped from the creek by a piston pump, and a pressure of 150 p.s.i. at the drills was maintained by a pressure regulator. Bit life averaged 180 feet, or 2-1/2 bits per cut. Carset bits (Ingersoll-Rand tungsten carbide inserts) were used in the chert and sandstone, and jack bits (Ingersoll-Rand hardened steel) were used in the shale. Records of purchases of supplies indicate that from 3 to 4 inches of drill steel was required for each foot of shaft for breakage, reshanking, etc.

An electric cable extending to the shaft bottom from a 15-kv.a. transformer on the surface furnished power for lights to all operations except loading explosives and blasting. This power was cut off and the drilling equipment was removed from the shaft before the explosives and detonators were lowered to the shaft bottom. The blasting switch, which was connected to 220-volt a.c. power at the surface, was inspected to see that it was in the "off" position, and that the blasting cable was disconnected and properly shunted. Battery lights were used while the drill holes were being loaded. From 225 to 350 pounds of du Pont 40-percent special gelatin explosive was

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used for each cut, depending on the depth of the cut. Millisecond-delay electric detonators were used to time each phase of the blast. The proper detonator was placed in the second cartridge of each charge. A typical 10-foot cut required 350 pounds of explosives and was charged as follows:

Hole position	Number of holes	Explosive in each hole, lb.	Millisecond delay detonator
Buster.....	1	4	0
Cut.....	6	8	50
First relief.....	10	7	100
Second relief.....	16	6	150
Line.....	22	6	200

While the holes were being loaded and tamped with loose sand, a man held the lead wires apart from any possible contact with leg wires as an added precaution. The leg wires from the caps were connected in a parallel-series circuit containing five series with the usual arrangement of approximately balancing the series circuits. The circuits were inspected and tested with a galvanometer. After connection to the blasting cable, the men were hoisted from the shaft. When all were accounted for, the blasting cable was connected at the surface, and the charge was detonated by engaging the switch.

Mucking and Scaling

Mucking was done on the day shift and was supervised by a foreman with a hoistman, a topman, and a truckdriver on the surface, and a miner, a tugger operator, and two muckers underground. The miner kept the walls scaled, and the two muckers handled the mucking machine and other equipment. The tugger operator controlled the operation of the mucking machine from the shaft bottom by a remote-controlled 12-volt electric circuit, thus eliminating the hazard of misinterpreted signals for operation of the clamshell that was part of the machine. The clamshell was powered by two air motors, which were equipped with solenoids for control through the 12-volt electric circuit (figs. 11 and 12). One motor controlled the opening and closing of the clamshell. The other hoisted and lowered the open clamshell.

The rope on the clamshell control passed through a block and tackle to give added closing force to the clam without excessive hoisting motion. The mucking operation commenced with supporting the weight of the clamshell with the holding rope and releasing the closing rope through block and tackle, allowing the clam to open by action of gravity. The open clam was dropped on the muck and closed by action of the closing rope through the block and tackle. After the clam was closed, continued action by the closing rope raised the clamshell over the hoisting bucket, and the clamshell was unloaded by holding with the holding rope and releasing the closing rope, allowing the clamshell to open. The empty and open clam, supported by the holding rope, was then dropped on the muck to begin another cycle. Horizontal movement of the clam was partly controlled by the physical effort of the two muckers, who positioned the clamshell by means of two ropes fastened to each end of the clamshell. While sinking the first 300 feet of shaft, the tuggers were

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mounted on surface supports. After that, convenient recesses were temporarily left in the shaft lining for tugger supports, permitting closer operation to the advancing shaft bottom.

The loaded 2-cubic-yard bucket was hoisted to the surface by a 300 hp. hoist equipped with a nonrotating wire rope to compensate for the lack of guides. After reaching the proper position in the headframe, the loose end of a 17-foot wire rope fastened to a beam was hooked to the bail by the topman, and as the hoist rope was slackened, the bucket swung downward and outward from the shaft to a position for unloading into the dump truck. (See

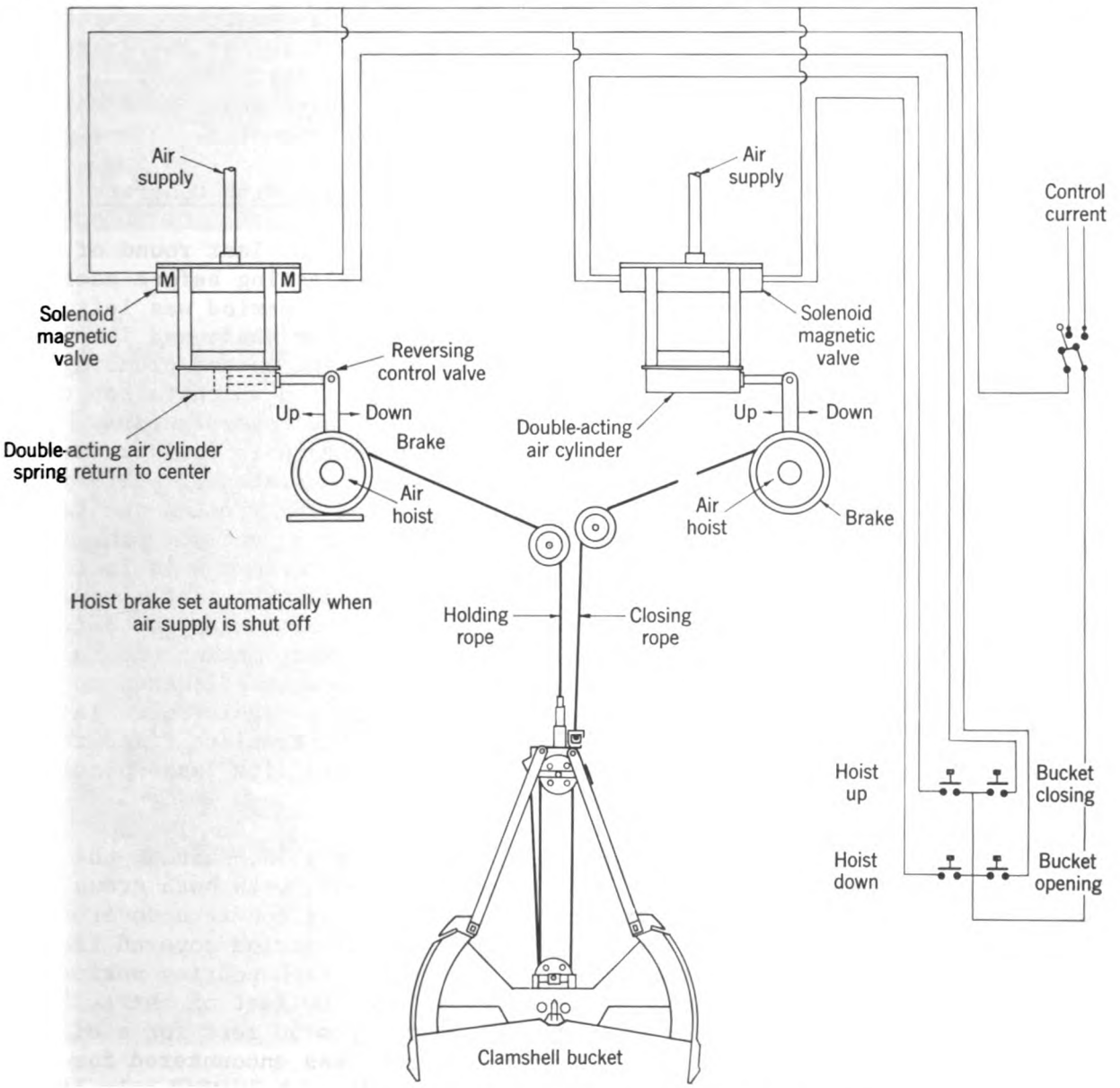

FIGURE 11. - Schematic Sketch Showing Mucking Machine.
(Data furnished by Cowin and Co.)

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FIGURE 12. - View of Clamshell Used on Mucking Machines.

fig. 5.) The bucket was dumped by opening side latches which permitted the bucket to overturn on the axis of the bail support. After the load was dumped, the bucket swung back to an upright position, and the side latches were fastened (fig. 13). The axis of the bail support was located between the centers of gravity of the loaded bucket and the empty bucket, which caused the dumping action to take place. The men in the shaft were protected from falling debris by air-operated shaft doors. The truckdriver hauled the loaded material to the dump site.

Lining Shaft With Concrete

Muck from the last round of drilling and blasting before each concrete-pouring period was left in the bottom of the shaft and leveled to permit setting up and plumbing a wooden template on which to set the steel-fabricated concrete forms, which were made up in two sections. Each section consisted of one 9-inch-wide key panel for freeing the form from the concrete, and six panels of a common width to form a 16-foot-diameter circle. The panels were 10 feet high in one section and 8 feet high in the other, making the fully assembled circular form 18 feet high (fig. 14). The forms were lowered to the template by a 100-hp. auxiliary hoist and assembled. Four double-screw jacks were used to space the opening for the 9-inch panel. The template fixed the position of the bottom of the form, and the top was alined with jacks placed against the shaft walls.

The 40-foot-deep shaft collar was completed in June 1955. Lining the main body of the shaft with concrete began August 5, 1955, with both crews, totaling 15 men, reporting on the day shift. Each pour of concrete covered from 10 to 17 feet of shaft, and each continuous pouring period covered from 10 to 260 feet of shaft, depending on rock conditions. Each pouring period between the 300- and the 940-foot depth covered 100 to 200 feet of shaft, below which the length of shaft per pouring period averaged 50 feet for a distance of 400 feet. At a depth of 1,340 feet weak rock was encountered for a distance of 125 feet, and the pouring periods were reduced to cover only 10 to 34 feet of shaft. Stronger rock (Fort Payne Chert) was encountered at a depth of 1,465 feet, and each pouring period after that covered an average depth of 50 feet. The last pour was made September 17, 1956.

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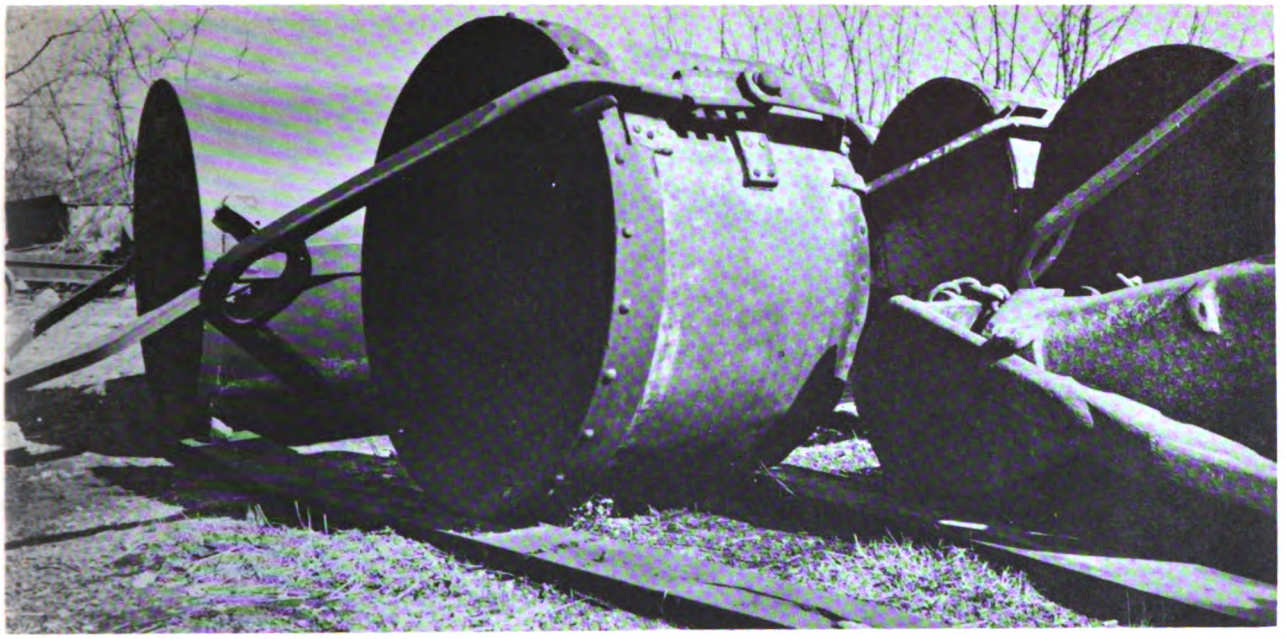

FIGURE 13. - View of Shaft Bucket.

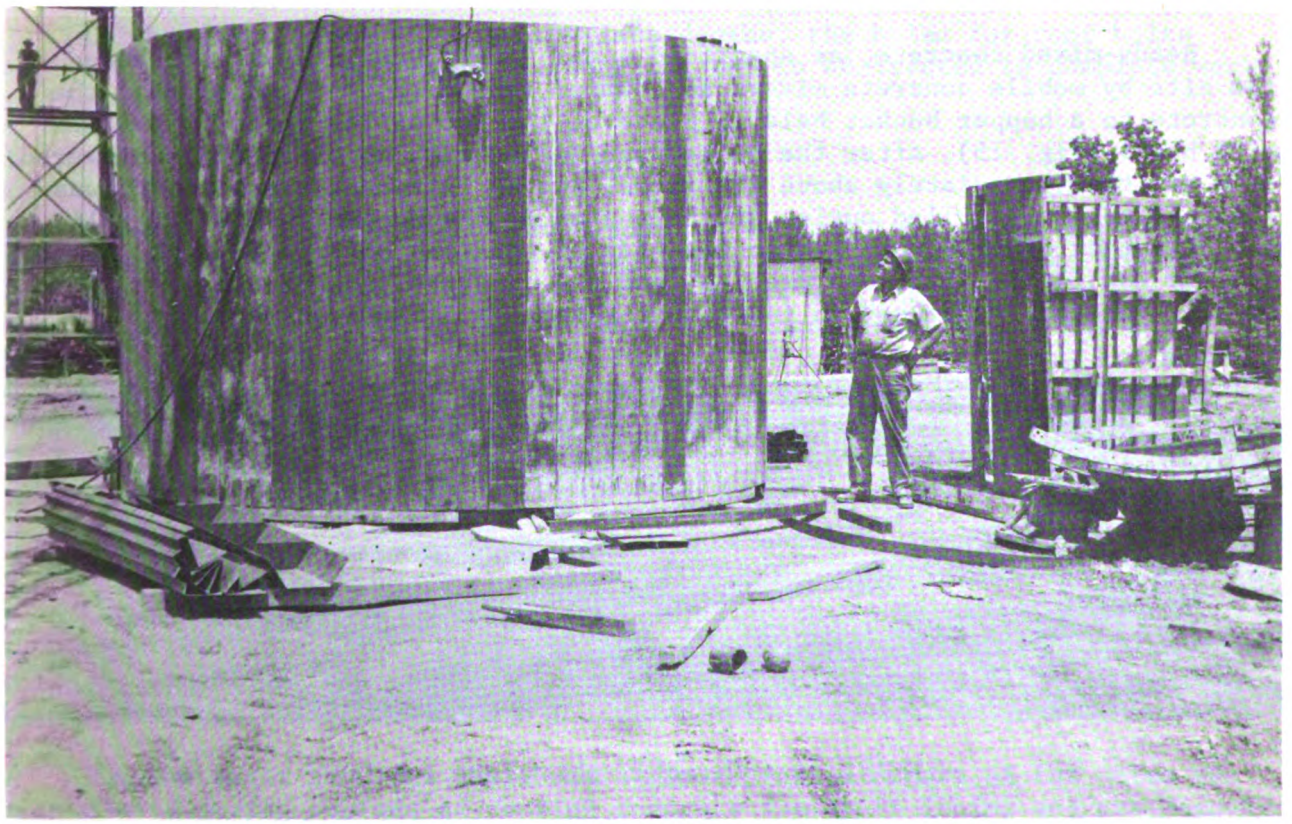

FIGURE 14. - View of Circular Steel Forms for Concrete Shaft Lining.

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FIGURE 15. - View of Concrete Hopper Bucket.

Ready-mixed concrete, as specified under "Shaft Design," was delivered to the site by mobile concrete mixers and dumped into a chute which carried the concrete to a hopper bucket held in place at the top of the shaft by two men with hooks (fig. 15). After the bucket was filled with concrete it was lowered to a position immediately above the forms, and an "elephant trunk spout" was fastened to a controlled outlet at the bottom of the hopper bucket (fig. 16). The "elephant trunk spout," which was made of sections of tapered pipe joined loosely for flexibility, was used to feed the concrete back of the form. Two impact vibrators were used to increase the density of the concrete.

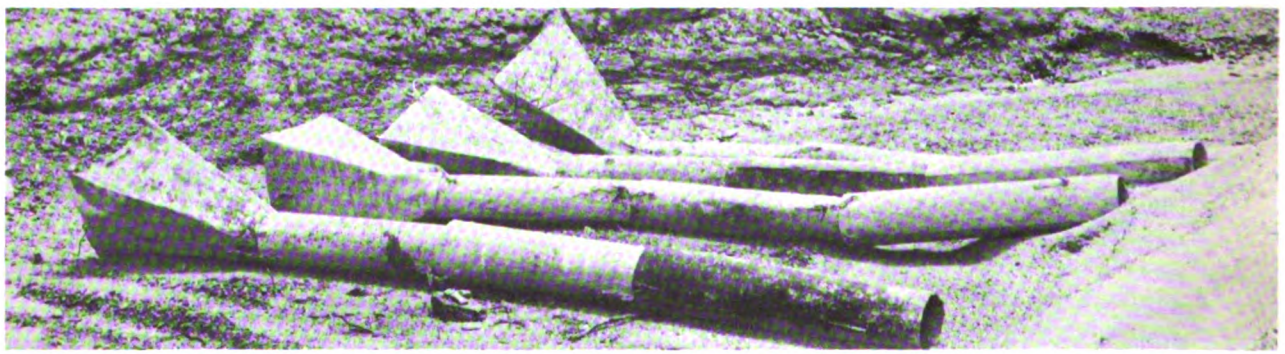

FIGURE 16. - View of Elephant Trunk Spout.

Holes 12 inches from the top of the form provided for 12 1-inch-diameter bolts to be placed in the concrete for use in supporting and lining up the bottom of the form when it was raised to the next position, and created a 1-foot overlap for each subsequent move. Each pour advanced the lining 17 feet, requiring a full 8-hour shift of the entire crew, scheduled as follows:

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Raising form..... 7:00 a.m. - 10:30 a.m.
Plumbing form.....10:30 a.m. - 12:00 noon
Concrete delivered...12:00 noon
Pouring concrete.....12:30 p.m. - 4:30 p.m.

Sometimes the shift extended beyond 4:30 p.m. in order to complete the pour. After the first pour of each continuous pouring period, a safety net was fastened to the bottom of the form.

Shaft Bottom

Expansion of the shaft walls for the bottom began August 10, 1956, at a depth of 1,654 feet (fig. 6). Before belling out, holes were drilled with a diamond drill to ascertain the exact top of the ore so that the shaft lining could be terminated 16 feet above the ore.

In sinking this section, the standard drilling pattern was abandoned, and the number of holes per drilling shift varied between 28 and 96, depending on condition of the face. The expanding bottom created a comparatively restricted free face, which interfered with proper breakage and led to poorly defined drilling faces, necessitating irregular cuts.

As the shaft advanced to appropriate depths, the holes for roof bolts were drilled in both curved backs. Staging had to be erected to complete work on the shaft bottom.

DISMANTLING

Dismantling and removal of shaft-sinking equipment commenced September 13, 1956, with removal of ventilation tubes before the shaft bottom was entirely finished. By September 24, all work on the shaft was completed, and the full time of the crew was used for dismantling buildings, headframe, etc., and transporting all equipment and accessories to the contractor's shop and storage yard. By October 9, 1956, the contractor had cleaned up the surface in the vicinity of the shaft portal and left the premises.

AUXILIARY FACILITIES

Pumping

A gasoline-driven piston pump was set up on the bank of the creek within 1,000 feet of the shaft to supply water to the drilling machines, change house, etc. A 1-inch line was laid to the change house and the shaft collar and continued down the shaft.

Pumping water from the shaft was a minor problem. Most of the water was accumulated during periods of pouring concrete for shaft lining and was removed by using a sump pump to fill the shaft bucket, which was hoisted to the surface. About 180,000 gallons, or approximately 100 gallons per foot of shaft, was removed in this manner. The water that accumulated when the shaft was advancing was removed with the muck.

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Ventilation

The shaft was ventilated temporarily by a 25-hp. Coppus blower fan located on the surface 50 feet from the shaft. This furnished 7,000 cubic feet of air per minute. An 18-inch ventilating tube was used to carry air to the men working in the shaft. The end of the tubing was kept about 25 feet above the men.

Safety

Safety precautions were described in the preceding pages, except for the usual hard hats and shoes with hard toes. The only lost-time accident occurred when a man injured his hand after stepping on an unfastened plank and falling 7 feet.

COSTS IN UNITS OF LABOR AND SUPPLIES

The direct costs of sinking the shaft in units of labor, supplies, and material are summarized in tables 2 and 3. Table 4 shows the number of shifts required for each phase.

Factual and Calculated Data

Table 5 shows a breakdown of the concrete, grout, and gunite used and the amount of dirt and rock excavated during the various phases of the operation.

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TABLE 2. - Distribution of direct man-hours

Item	Man-hours	Man-hours per ft. of item	Man-hours per ft. of shaft
Surface installations:			
Supervision	378	-	.22
Grouting unconsolidated material	181	-	.11
General preparation and building	1,460	-	.87
Temporary headframe and collar1/	433	-	.26
Miscellaneous	273	-	.16
Total	2,725	-	1.62
Shaft sinking:			
Supervision	3,482	2.16	2.07
Hoisting	3,446	2.13	2.05
Drilling	8,853	5.48	5.27
Mucking and scaling	7,855	4.87	4.68
Rock disposal	3,370	2.09	2.00
Miscellaneous	336	.21	.20
Total	27,342	16.94	16.27
Shaft-lining installations:			
Supervision	2,134	1.32	1.27
Hoisting	2,457	1.52	1.46
Installing forms	2,600	1.61	1.55
Pouring concrete	7,009	4.34	4.17
Removing forms	2,567	1.59	1.53
Miscellaneous	167	.11	.10
Total	16,934	10.49	10.08
Preparation of bottom level:			
Supervision	300		
Hoisting	300		
Drilling	545		
Mucking out bell and scaling	677		
Disposing rock	223		
Diamond drilling	64		
Guniting	410		
Grouting	40		
Miscellaneous	117		
Total	2,676	103.0	1.59
Dismantling:			
Supervision	156	-	
Hoisting	56	-	
Labor	808	-	
Total	1,020	-	.61
Total labor	44,247	-	26.34
Total supervision	6,450	-	3.84
Grand total	50,697	-	30.18

1/ Does not include subcontractor's time to excavate material.

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TABLE 3. - Materials and supplies

	Amount	Amount per ft. of item	Amount per ft. of total shaft
Concrete:			
Foundations for temporary buildings...cubic yards	6		
Shaft collar (40 ft.).....do...	175	4.3	
Shaft lining (main body, 1,614 ft.).....do...	4,461	2.76	
Total shaft (1,680 ft.).....do...	4,636	-	2.76
Cement:			
Grouting, surface.....bags	702	-	
Grouting, main body of shaft .....do...	221	-	
Guniting, shaft bottom.....do...	233	-	
Total.....do...	1,156	-	0.69
Bentonite: Grouting.....do...	30	-	0.02
Sand:			
Grouting.....cubic yards	34	-	-
Guniting.....do...	26	-	-
Total.....do...	60	-	-
Drilling supplies:			
Bits, tungsten carbide (carset).....	366	-	
Bits, hardened steel (jack).....	144	-	
Total bits.....	510	-	0.32
Drill steel.....feet	490	-	0.29
Explosives:			
Dynamite (40 percent special gelatin):			
Collar excavation.....pounds			
Shaft excavation.....do...	60,600	37.55	
Bottom-level excavation.....do...	2,450	94.23	
Total.....do...	63,050	-	37.53
Detonators:			
Collar excavation.....	-	-	-
Shaft excavation.....	12,216	7.56	
Bottom level.....	784	30.15	
Total.....	13,000	-	7.74
Connecting wire.....pounds	225	-	-
Roof bolts:			
Shaft bottom, 5-foot.....	46	-	-
Shaft bottom, 8-foot.....	10	-	-

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TABLE 4. - Shifts

	Days	Nights
Surface installations	46	-
Shaft sinking:		
Drilling and blasting	-	195
Mucking and scaling	205	-
Shaft-lining installation	152	50
Shaft bottom:		
Drilling	-	14
Mucking and scaling	15	-
Others	7	3
Dismantling	21	-
Total	446	262

TABLE 5. - Factual and calculated data

Excavating

	Linear feet	Cubic yards	
		Dirt	Rock[1]
Shaft collar	40	253	189
Main body of shaft	1,614	-	16,481
Shaft bottom	26	-	600
Total[2]	1,680	253	17,270

Grouting

	Holes	Linear feet	Bags of cement	Sand, cubic yards
Surface	4	591	702	26
Shaft	1	18	221	8
Total	5	609	923	34

Concrete, shaft lining

	Vertical feet	Cubic yards
Collar	40	175
Main body	1,614	4,460
Total	1,654	4,635

Guniting, distance and materials used

Shaft bottom...26 vertical feet..233 bags of cement and 26 cubic yards of sand

Diamond drilling, distance

Shaft bottom..... 60 linear feet

Surface.....591 linear feet

1/ In place.

2/ Total cubic yards excavated, 17,523.

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APPENDIX

Calculations for Drilling Procedure (Based on data derived from figures 10 and 11)

Data

Description	Inches
Radius of shaft	108
Minimum clearance from center of back end of drill carriage to wall of shaft	6
Height of center of arm socket at swivel above bottom of jumbo	120
Distance from center of jumbo to center of swivel	15
Length of arm	85-1/2
Distance (normal to drilling machine) from joint-regulating angle between arm and drill carriage to centerline of drilling machine	10
Length of drill carriage plus clearance above shaft bottom for cut holes	140
Depth of cut	120
Depth of sump	18

Symbols for Calculating Measurements (All linear measurements are in inches)

A = Angle of hole from vertical.

B = Angle between the extended centerline of the arm and the centerline of the drill carriage projected in the plane of the arm and the centerline of the shaft.

a = Horizontal distance from shaft centerline to bottom of hole.

b = Length of hole.

c = Distance between center of jumbo and center of swivel or projection of same on plane of drill carriage and centerline of shaft.

d = Distance from centerline of shaft to center of collars of drill holes.

e = Vertical depth of bottom of hole, including sump where desired.

g = Distance between the bottoms of holes in each circle.

h = Distance between the tops of holes in each circle.

n = Number of holes in each circle.

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Calculations for Cut Holes

Find A, B, and d for cut holes at center of drilling quadrant.

Desired depth: 120 in. + 18 in. = 138 in.

Distance from center of back end of drill carriage to centerline of shaft: 108 in. - 6 in. = 102 in.

$$\frac{102}{d} = \frac{140 + b}{b} \qquad b^2 = d^2 + 138^2$$

$$b = \frac{140d}{102 - d} \qquad b = \sqrt{d^2 + (138)^2}$$

equating

$$\frac{140d}{102 - d} = \sqrt{d^2 + (138)^2}.$$

For calculating convenience reduce scale to 1/100, then

$$\frac{1.40d_1}{1.02-d_1} = \sqrt{d_1^2 + (1.38)^2}$$

$$d_1^4 - 2.04d_1^3 + .98d_1^2 - 3.88d_1 + 1.98 = 0 = f(d_1)$$

$$4d_1^3 - 6.12d_1^2 + 1.96d_1 - 3.88 = 0 = f'(d_1).$$

Assume $d_2 = .50$ (Newton's method):

$$d_1 = d_2 - \frac{f(d_2)}{f'(d_2)}$$

$$d_1 = .5236.$$

Multiply by 100 to correct for calculating convenience:

$$d = 52.36 \text{ in.}$$

$$A = \tan.^{-1} \frac{52.4}{138} = 20.8°$$

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Let $90° - \tan.^{-1} \frac{120}{52.4 - 15} + 20.8° = M$:

$$\frac{\text{Sin } B_1}{\text{Sin } M} = \frac{\sqrt{120^2 + (52.4 - 15)^2} - \frac{10}{\text{Sin } M}}{85.5}$$

$$B = B_1 = \sin^{-1} \frac{\sqrt{(120)^2 + (52.4 - 15)^2}\, \sin(90° - \tan.^{-1} \frac{120}{52.4 - 15} + 20.8°) - 10}{85.5}$$

$$B = 52°.$$

Find A, b, and d for cut holes 30° from center of drilling quadrant.

Set B at 52°.

Desired depth: e = 120 in. + 18 in. = 138 in.

c = 15 cos. 30° = 13 in.

$$A = \tan.^{-1} \frac{13}{120 + 138} + \sin.^{-1} \frac{85.5 \text{ sin. } 52° + 10}{\sqrt{(120 + 138)^2 + (13)^2}}$$

A = 20.3°

$$b = \frac{138}{\text{cos. } 20.3°} = 147 \text{ in.}$$

d = 138 tan. 20.3° = 51 in.

n = 6 (selected for best distribution of explosive).

h = d = 51 in. (definition of a hexagon).

The following formulas based on the preceding data and definitions of symbols are used to calculate angles and distances of drill-set-up adjustments:

$$A = \text{Sin}^{-1} \frac{85.5 \text{ sin } B + 10}{\sqrt{(120 + e)^2 + (a - c)^2}} + \tan.^{-1} \frac{120 + e}{a - c} - 90°$$

$b = e/\cos A$

$d = a + e \tan A$

$$n = \frac{360°}{2 \sin^{-1} (g/2a)}$$

$h = 2d \sin 360°/2n.$

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Find A, b, and d for first-relief holes in center of drilling quadrant, and n and h for all first-relief holes.

Set B at 52°.

c = 15 in.

Desired that at a vertical depth of 120 in. the distance from the centerline of the shaft to center of hole is 42 in.,

then A = 12.3°,

and extending the vertical depth to allow for a sump

e = 120 in. + 18 in. = 138 in.,

a = 38 in.,

b = 141 in.,

d = 68 in.

Desired that g = 26 in.,

then n = 10

h = 42 in.

Find A, b, and d for first-relief holes 36° from center of drilling quadrant.

Set B at 52°.

c = 15 cos 36° = 12 in.

Desired that at a vertical depth of 120 in. the distance from the shaft centerline to center of hole is 42 in.,

then A = 11.6°,

and extending vertical depth to allow for a sump

e = 120 in. + 18 in. = 138 in.,

a = 38 in.,

b = 141 in.,

d = 66 in.

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Find A, b, and d for second-relief holes 11.3° from center of drilling quadrant, and n and h for all second-relief holes.

Set B at 52°.

c = 15 cos 11.3° , 14.7 in.

Desired that e = 120 in.,

and that a = 78 in.,

then A = 3.4°,

b = 120 in.,

d = 85 in.

Desired that g = 30-1/2 in.,

then n = 16

h = 33 in.

Find A, b, and d for second-relief holes 34° from center of drilling quadrant.

Set B at 52°.

c = 15 cos 34° = 12.4 in.

Desired that e = 120 in.,

and that a = 78 in.,

then A = 2.8°,

b = 120 in.,

d = 84 in.

Find A, b, and d for ring hole in center of drilling quadrant and n and h for all ring holes.

Set B at 52°.

c = 15 in.

Desired that e = 120 in.,

and that a = 112 in.,

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then $A = -4.6°$,

$b = 120$ in.

$d = a + (-e \tan A) = 102\text{-}1/2$ in.

Desired that $g = 32$ in.,

then $n = 22$,

$h = 29$ in.

Find a, b, and d for ring holes 24.5° from center of drilling quadrant and keep A at -4.6°.

Set B at 52°.

Desired that $e = 120$ in.,

then $$d = \frac{(102.5 - 15) \sin (180° - 24.5° - \sin^{-1} \frac{15 \sin 24.5°}{102.5 - 15}}{\sin 24.5°},$$

$d = 101$ in.,

$c = 15 \cos 24.5° = \underline{13.6 \text{ in.}}$,

$a = 101 + 120 \tan. 4.6°$,

$a = 111$ in.

Find A, b, and d for ring holes 41° from center of drilling quadrant.

Set B at 52°.

$c = 15 \cos 41° = 11.3$ in.

Desired that $e = 120$ in.,

and that $a = 111$ in.,

then $A = -5.3°$,

$b = 121$ in.,

$d = a + (-e \tan A) = 100$ in.

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